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A PILOT STUDY OF AIR POLLUTION IN PROVIDENCE, RHODE ISLAND

Marvin D. High, et al

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

June 1962

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A PILOT STUDY OF AIR POLLUTION

PROVIDENCE, RHODE ISLAND

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A Joint Study by the City of Providence
and the Public Health Service.

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A PILOT STUDY OF AIR POLLUTION IN PROVIDENCE, RHODE ISLAND

Marvin D. High and Robert W. Slater

Technical Assistance Branch
Division of Air Pollution
Public Health Service
U. S. Department of Health, Education and Welfare

and

Genaro G. Costantino, Chief

Division of Air Pollution and
Mechanical Equipment and Installations
City of Providence

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

June 1962

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A PILOT STUDY OF AIR POLLUTION IN PROVIDENCE, RHODE ISLAND

SUMMARY

Air pollution control in Providence dates from 1947 when ordinances were enacted to control smoke from soft coal combustion. Regulations established in 1956 banned open burning and regulated emission of smoke, soot, fly ash, and noxious vapors and gases.

The continued effort of the City to maintain desirable air quality through an effective air pollution control program resulted in a study of existing and potential levels of pollution. The study was conducted, with the assistance of the Public Health Service, in two equal periods covering 15 sampling days each, July 31 through August 18 and October 31 through November 17, 1961. Air samples collected at a centrally located downtown station were analyzed for soiling, suspended particulates, dustfall, sulfur dioxide, oxides of nitrogen, total oxidants, and carbon monoxide.

Meteorological data for the sampling periods were analyzed and then compared with long-term data for the respective sampling periods. The sampling data were representative of average, or normal, weather data; thus, interpretation and extension of present air quality data can be made for a longer period of time.

Particulate loadings in the Providence atmosphere were low. The average value for soiling index over both sampling phases was 0.7 Cohs per 1000 linear feet, which, described subjectively, is considered light. Weight of suspended particulate matter in the summer averaged 76 micrograms per cubic meter ($\mu g/m^3$), ranging from 33 to 136 $\mu g/m^3$. November samples averaged 89 $\mu g/m^3$, ranging from 56 to 148 $\mu g/m^3$. In each case these loadings are less than in other cities of comparable size and less than the average for cities in the New England area. Dustfall measured 18.7 and 21.3 tons per square mile per month, respectively, for the August and November sampling periods. These values are considered low for a downtown commercial area in a city the size of Providence.

Sulfur dioxide levels in the summer were extremely low, averaging 0.02 parts per million (ppm), as might be expected in the absence of fuel combustion for heating. November samples averaged 0.07 ppm, ranging from near zero to 0.19 ppm.

Evidence of the occurrence of Los Angeles type photochemical smog was demonstrated during both phases of sampling, but was most pronounced in the summer phase. Summer oxidant levels (as measured by the phenolphthalin method) ranged from 0.01 to 0.27 ppm, averaging 0.07 ppm for all samples. Autumn levels, as expected, were lower. The average was 0.04 ppm, ranging from near zero to 0.16 ppm. The maximum summer level of 0.27 ppm is approximately equal to the level 0.30 ppm that causes damage to vegetation, eye irritation, rubber cracking, and visibility reduction. Oxides of nitrogen, which contribute to the formation of photochemical smog, showed high concentrations of the days that oxidant levels were high. Carbon monoxide, which arises primarily from automobiles, showed concurrently high levels with oxidants and oxides of nitrogen, but on the average concentrations were quite low.

Meteorological studies made by other investigators indicate that Providence can expect temperature inversions to exist about 25 percent of the time during a year. The most severe season is the fall when inversions exist nearly one-third of the time. The most enduring inversions also occur in the fall with 10 percent lasting 19 hours or longer.

Based on the sampling results and the meteorological data available for the area, oxidant levels sufficient to cause damage to vegetation, eye irritation, rubber cracking, and visibility reduction may be predicted to occur from time to time in the summer months. Relatively high levels of sulfur dioxide, oxides of nitrogen, and particulate matter, equal to or greater than the maximums found in this study, may be expected to occur about 10 percent of the time during the winter months. Every 2 years or so a stagnant air mass that may cause an extraordinary build-up of pollution may be expected to occur. Under these stagnation conditions, undue discomfort and annoyances might prevail for the inhabitants in the area for 4 or more days.

RECOMMENDATIONS

Based on the results of this study, analysis of local meteorological data, and the present technical knowledge of the growing problem of air pollution, it is recommended that the City of Providence:

1. Continue its effective program for control of air pollution.
2. Continue to evaluate the need for control of emissions from the handling and use of automotive fuels.
3. Keep advised of research and field study efforts to control emissions of oxides of nitrogen and disseminate this information to appropriate parties.
4. Conduct a long-term air pollution monitoring program, in addition to participating in the National Air Sampling Network, to delineate the problem more fully, to assess the need for effecting various control activities, and to follow trends in air pollution levels.

INTRODUCTION

Providence, Rhode Island, one of our Nation's first cities, was also one of the forerunners in the control of air pollution. In 1947, interested civic organizations initiated action that led to enactment and enforcement of a smoke ordinance directed mainly toward regulation of smoke emission from use of soft coal. An intensive program of air pollution control was initiated in 1956 when new air pollution regulations were established. These regulations banned all open burning within the City, and set up limitations on emission of smoke, soot, and fly ash, as well as on noxious and noisome vapors and gases.

Also in 1956, the City joined the National Air Sampling Network conducted by the U. S. Public Health Service to monitor suspended particulate matter in the air. More recently the City began monitoring gaseous pollutants in cooperation with the "Network." Results from these gaseous pollutant measurements are not yet available, but data for weight of suspended particulate matter show that Providence is relatively clean, compared with other United States cities of similar size. These and other data indicate the exemplary work of the air pollution control program of Providence in controlling particulate emissions.

More recent interest and concern with gaseous pollutant emissions and means for their control are evidenced by the fact that crankcase blow-by control devices have been installed on vehicles owned by the City and those owned by employees of the City. The local utility companies are also cooperating in this effort by installing blow-by control devices on a limited number of vehicles. This is expected to provide additional data and information to the Division of Air Pollution and Mechanical Equipment and Installations. An evaluation of several devices will be made, however, before their use is recommended to the general public in Providence.

This continued effort to maintain an effective air pollution control program in Providence was, in part, responsible for this cooperative study to evaluate pollution levels in Providence.

STUDY PROCEDURE

The Providence study covered two equal periods of 15 sampling days each. The first phase was conducted July 31 through August 18, 1961. Samples were collected only on weekdays, Monday through Friday, at 2-hour intervals, from 6 am through 2 pm, Eastern daylight time.

The second phase of the study was conducted October 31 through November 17, 1961. One Saturday was included with 14 weekdays

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for this schedule. Sampling was performed every 2 hours from 8 am to 4 pm, Eastern standard time. During each phase, around-the-clock sampling was carried out on three consecutive days, resulting in 78 hours of continuous bi-hourly data for each season.

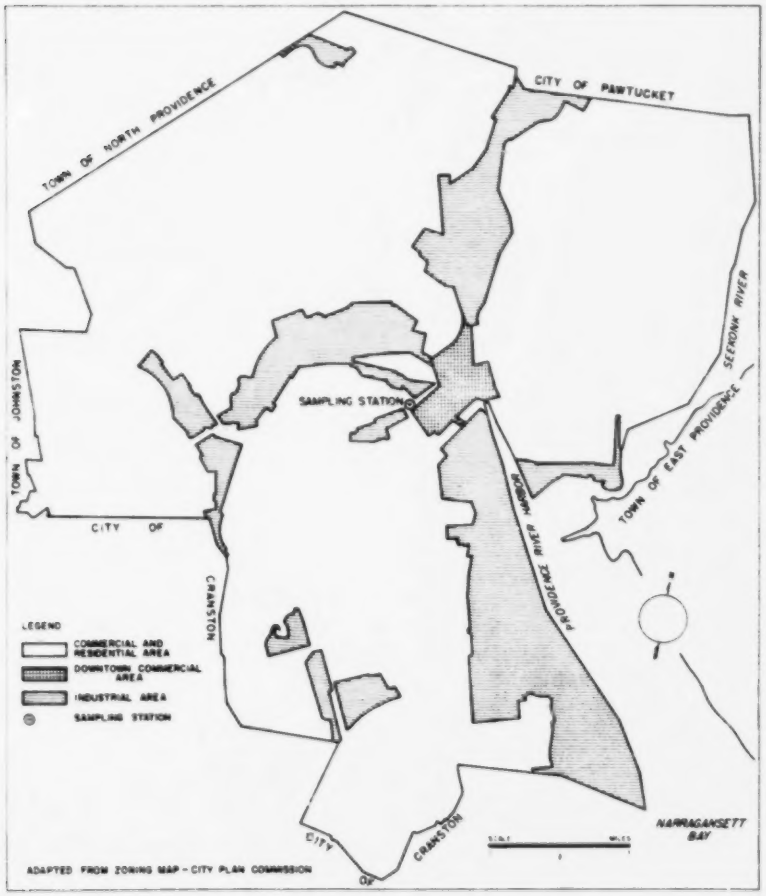

Figure 1. Location of sampling station with respect to major land use zones in Providence

The sampling site was the roof of the Central Police and Fire Station at the corner of Empire and Fountain Streets, LaSalle Square, 45 feet above ground level (Figure 1). This site is representative of conditions in the central part of the City, since it is on the periphery of the downtown commercial area, adjacent to a residential area, and near industrial operations. [1]

Samples were collected for determination of sulfur dioxide, nitric oxide, nitrogen dioxide, carbon monoxide, and total oxidants, on a bi-hourly basis. Visibility from the sampling site was determined on the same schedule; photographs were taken to document visiblity restrictions.

Particulate pollution levels were monitored continuously in three ways. Soiling index was determined with the AISI strip filter paper sampler with a 4-hour sampling time; suspended particulates were collected on a 24-hour basis for determination of total weight; and a single dustfall sample was collected over the entire period of each phase of the study.

A summary of the methods of measurement (described in detail in Appendix B) and primary sources of pollutants follow:

Pollutants	Sources of pollutant	Method of measurement
Oxidant	Photochemical reactions	Phenolphthalin method
Nitric oxide, Nitrogen dioxide	Combustion processes and motor vehicle exhaust	Saltzman method, including oxidation of NO to NO_2
Carbon monoxide	Largely motor vehicle exhaust; some from combustion processes	Adaptation of NBS detector tube technique
Sulfur dioxide	Combustion of sulfur-containing fuels	West-Gaeke method
Particulate matter	Combustion processes	1. AISI strip filter paper sampler 2. High-volume filter 3. Dustfall

DISCUSSION OF RESULTS

PARTICULATE POLLUTANTS

In general particulate loadings in the Providence atmosphere were found to be low, reflecting the effectiveness of the local air pollution control program in controlling smoke, dust, and other particulate emissions. Three indices of particulate pollution levels were measured, namely, soiling index, suspended particulate loading, and dustfall rate.

Soiling Index

The soiling index is a measure of the soiling characteristics of very small suspended particulates in the air. Samples of air are drawn through filter paper, and the optical density of the dirty spot is determined. The values are recorded in Cohs* per 1000 linear feet of filtered air.

*One Coh unit is that quantity of particulate matter which produces an optical density of 0.01 on filter paper.

The Cohs rating system, which follows, for describing soiling index measurements subjectively was devised by the New Jersey State Department of Health:[2]

Cohs per 1000 linear feet	Rating
0 - 0.9	Light
1.0 - 1.9	Moderate
2.0 - 2.9	Heavy
3.0 - 3.9	Very heavy
4.0 - plus	Extremely heavy

The average soiling index value during the study was 0.7 Cohs per 1000 linear feet of air, showing a light loading of small particulates in Providence. Of 210 samples collected, 182 were below 1.0 Coh per 1000 linear feet of air, 26 were in the range of 1.0 - 1.9, and only 2 were above 2.0.

Total Suspended Particulates

Total suspended particulate values are a measure of the weight of particles in the air. These particles arise from incomplete fuel combustion, industrial processes, and other sources. These particles are relatively small and are carried in the air for a long time.

Particulate concentrations in the summer phase of the study ranged from 33 to 136 $\mu g/m^3$ of air, with an average of 76. In the autumn phase, values ranged from 56 to 148 $\mu g/m^3$ of air, with an average of 89. This seasonal variation is attributable to the increased consumption of fuel in the heating season. Later in the heating season, during the colder days of December through February, even higher concentration might prevail.

Suspended particulate measurements show that the air over Providence is relatively clean, compared to the New England States or to other cities of similar size. A survey of data for 1954-1957 shows that the average particulate loading over cities in the New England States was 118 $\mu g/m^3$ of air.[3] The average for 57 cities with populations of 100,000 to 400,000 was 119 $\mu g/m^3$ in 1960.[4]

Dustfall

Dustfall measurements indicate the amounts of heavy particles that settle from the air by gravity. In general, these particles settle a short distance from their source. Dustfall rates of urban areas vary, depending on area size, industrial activity, fuel-use patterns, and other factors. Average urban dustfall usually ranges from 25 to 75 tons per square mile per month.

Oregon is the only State that has set standards for dustfall.[5] There, dustfall more than 15 tons per square mile per month above

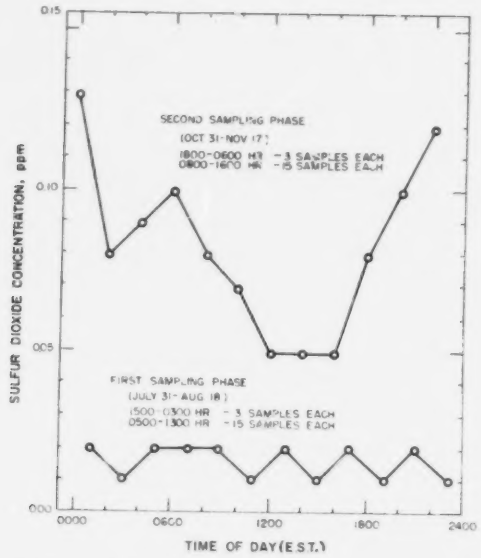

Figure 2. Diurnal variation of sulfur dioxide levels during summer and autumn sampling phases

normal background in residential areas is considered excessive. Similarly, dustfall more than 30 tons per square mile per month above background is considered excessive in industrial areas. The background level is determined in a nearby rural area. Depending upon their climate and geography, rural areas of Oregon usually have dustfall rates ranging from 5 to 10 tons per square mile per month.

During each phase of this study a single dustfall sample was collected at the fire station near the downtown commercial area. The sample was collected approximately 45 feet above street level. Street and ground dust stirred by wind and automobile traffic and dust from construction activities do not have as great an influence at the sampling level as at lower levels. For the August phase of sampling, the dustfall rate was 18.7 tons per square mile per month, and for the November phase, 21.3 tons per square mile per month, indicating that the downtown area of Providence, even with its proximity to some industrial zones, has a low level of dustfall.

GASEOUS POLLUTANTS

Sulfur Dioxide

A total of 191 samples were collected and analyzed for sulfur dioxide during the two phases of sampling. During the first phase of sampling, sulfur dioxide values ranged from near zero to a maximum of 0.07 ppm; the average was slightly less than 0.02

ppm. The second phase showed higher concentrations, mainly because of the onset of the heating season. During this period sulfur dioxide values ranged from near zero to a maximum of 0.19 ppm, with the average being 0.07 ppm.

The diurnal and seasonal variation in sulfur dioxide concentrations are presented graphically in Figure 2. The greatest average concentration for any given hour during the summer phase was 0.02 ppm. This is only 40 percent of the minimum average hourly concentration found during the warmer afternoon hours of the heating season. During the colder periods, with the greater need for space heating, values were sometimes higher than summer levels by a factor of ten. This seasonal variation in sulfur dioxide levels indicates that fuel burning for space heating is a primary source of sulfur dioxide in the air.

Maximum sulfur dioxide levels during the November sampling period were noted at night; minimums were recorded during the noon to mid-afternoon period. Two factors contribute to this var-

Table 1. RELATIONSHIP OF MAXIMUM AND MINIMUM SULFUR DIOXIDE LEVELS TO WEATHER CONDITONS - OCTOBER 31 TO NOVEMBER 18, 1961

Date	Time (EST)	Wind speed,[a] mph	Average daily temperature,[b] °F	Sulfur dioxide concentration, ppm
	Twelve Highest Values			
11/1	1200	18.4	47	0.13
11/6	0800	5.8	59	0.17
11/7	2000	8.1	50	0.16
	2200	9.2	50	0.16
11/8	0000	9.2	46	0.16
	1000	9.2	46	0.13
11/9	0600	12.7	37	0.13
	1800	17.3	37	0.13
	2200	11.5	37	0.15
11/10	0000	13.8	35	0.13
11/16	0800	calm	43	0.17
	1000	calm	43	0.19
Average		9.6	44.2	0.15
	Nine Lowest Values			
10/31	0800	5.8	60	0.02
	1200	23.0	60	0.02
	1400	17.3	60	0.01
	1600	13.8	60	0.02
11/1	1000	18.4	47	0.02
11/3	1200	18.4	51	0.01
11/11	1400	6.9	36	BMD[c]
11/15	1200	11.5	46	0.01
11/17	1200	11.5	52	0.01
Average		14.1	52.4	0.01

[a]Reference 7.
[b]Reference 6.
[c]BMD - Below minimum detectable limits of analytical method.

iation. Fuel consumption to meet space heating requirements is greatest at night when the coldest temperatures occur.[6] Secondly, dispersion and dilution of pollutants is greatest during the day. Average daytime wind speeds for November were 2.5 mph greater than nighttime wind speeds.[7] Also, the stability of the atmosphere is greatest at night, and thus vertical mixing of the air is reduced.

Wind and temperature effects are further evidenced in Table 1. The twelve highest sulfur dioxide values for the November sampling period occurred when the wind speed averaged 10 mph and the temperature averaged 44°F. Conversely, the nine lowest levels occurred when the wind speed averaged 14 mph and the temperature averaged 52°F. The maximum concentration of sulfur dioxide observed during the study was 0.19 ppm. This occurred at 10 am, November 16, preceding the breakup of an inversion that had persisted for 14 hours. These levels cannot be considered alarming.

The State of California selected a sulfur dioxide concentration of 0.3 ppm for an 8-hour period as its standard for ambient air quality.[8] For periods of 1 hour, .5 ppm was selected. The sulfur dioxide taste threshold of 0.3 ppm[9] was not detected during any of the thirty-minute samples taken in the Providence study, although short-term peaks certainly could have exceeded this value. It is unlikely that a concentration of 3.0 ppm (the odor threshold for sulfur dioxide[9]) was exceeded.

Total Oxidants

Total oxidant concentrations indicate the presence of photochemical smog in an atmosphere. This smog, first noted in Los Angeles, is produced in reactions between hydrocarbons, particularly olefins, and nitrogen oxides under suitable conditions of solar radiation. The reactions result in pollutants that cause adverse effects such as plant damage, rubber cracking, eye irritation, and visibility reduction.

Generally speaking, the principal source of atmospheric hydrocarbons in many cities is the automobile. Considerable amounts of hydrocarbons are discharged from automobile exhaust pipes, crankcase vents, carburetors, and gas tanks, and from gasoline handling and storage operations.

A total of 191 samples were collected and analyzed for oxidants (phenolphthalin method) during the two phases of sampling. During the summer, oxidant values ranged from 0.01 ppm to a maximum of 0.27 ppm, with an average of 0.07 ppm. Autumn samples showed lower concentrations, ranging from near zero to 0.16 ppm, with an average of 0.04 ppm. Oxidant levels varied with time of day (Figure 3). Since the reaction that causes formation of oxidants is promoted by sunlight, one would expect higher oxidant levels during periods of intense sunlight. The curve for the summer sampling period demonstrates this relationship

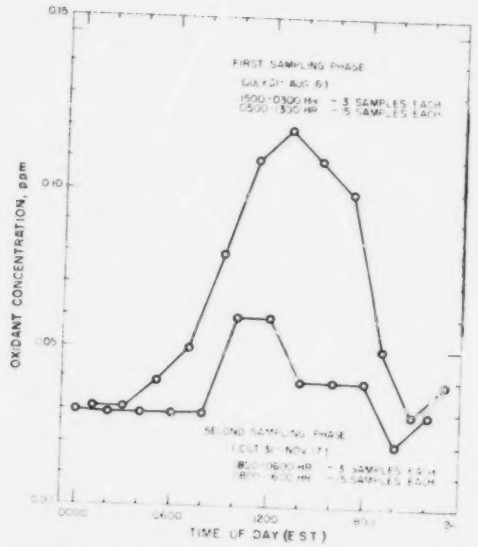

Figure 3. Diurnal variation of oxidant levels during summer and autumn sampling phases

very clearly. Oxidant values fall to their lowest level at night; they rise to a maximum at midday. As expected, maximum levels for oxidants occurred when the sun was at its highest point above the horizon.

Analyses of oxidant concentrations and concurrent weather data show that an air pollution build-up began during the evening of August 9, 1961. The maximum oxidant concentration of 0.27 ppm, which occurred at noon on August 10, is approximately equal to the level (0.3 ppm) that may cause damage to vegetation, eye irritation, rubber cracking, and visibility reduction. Meteorological conditions conducive to build-up of pollutants were indicated by low wind speeds and an atmospheric temperature inversion during the night of August 9-10 (Table 2). Elevated pollution levels were further evidenced by visibility reduction due to smoke and haze (Figure 4). Following sunrise, oxidant levels increased from 0.12 ppm at 0600 EDT to a maximum of 0.27 ppm at 1200 hours. This sequence of events demonstrates the formation of oxidants by the photochemical smog mechanism, as described for Los Angeles type pollution.

A similar but less-severe and shorter-term accumulation of pollutants, with an associated increase in oxidant levels, was noted during the autumn sampling period on November 16, 1961 (Table 2). The peak was 0.10 ppm, but no other significant levels were noted on that sampling day; however, the stability of the at-

Table 2. MAXIMUM OXIDANT CONCENTRATIONS AND WEATHER DATA RECORDED DURING PERIODS OF POLLUTION ACCUMULATION

Date	Local time[a]	Oxidant level, ppm	Wind direction[b]	Wind speed[b] mph	Stability class[c]	Visibility[b] miles	Visibility obstruction
Aug. 9	2000	--	SW	10.4	Neutral	7	None
	2100	--	SW	9.2	Slightly stable	7	None
	2200	--	SW	9.2	Slightly stable	7	None
Aug. 10	0000	--	WSW	18.1	Slightly stable	7	None
	0200	--	SSW	5.8	Stable	7	None
	0400	--	S	4.6	Stable	5	Haze
	0600	0.12	SSW	4.6	Stable	3	Ground fog
	0700	--	SSW	4.6	Neutral	3	Ground fog
	0800	0.18	S	4.6	Slightly unstable	3	Smoke, haze
	1000	0.14	S	5.8	Slightly unstable	4	Smoke, haze
	1200	0.27	S	13.8	Neutral	5	Smoke, haze
	1400	0.25	S	15.0	Neutral	5	Smoke, haze
Nov. 15	1600	0.04	N	4.6	Neutral	15	None
	1800	--	NNE	9.2	Slightly stable	7	None
	2000	--	N	4.6	Stable	5	Smoke, haze
	2200	--	NNW	4.6	Stable	4	Smoke, fog
Nov. 16	0000	--	NW	6.9	Stable	4	Smoke, fog
	0200	--	--	calm	Extremely stable	3	Smoke, fog
	0400	--	NNW	4.6	Stable	2	Smoke, fog
	0600	--	W	5.8	Stable	3	Smoke, fog
	0800	BMD[d]	--	calm	Slightly unstable	2	Smoke, fog
	1000	0.10	--	calm	Neutral	1.5	Smoke, fog
	1200	0.01	S	5.8	Neutral	4	Smoke
	1400	0.01	S	11.5	Neutral	8	None
	1600	BMD[d]	S	5.8	Neutral	10	None

[a]August is EDT; November is EST.
[b]At T.F. Green Airport (Reference 71).
[c]Determined by the method described by Turner (Reference 10).
[d]BMD - Below minimum detectable limits of analytical method.

mosphere, the light winds, and the visibility reduction all indicate the occurrence of a pollution build-up. In addition, maximum levels were observed for suspended particulate matter, soiling, sulfur dioxide, nitric oxide, and nitrogen dioxide.

Nitric Oxide - Nitrogen Dioxide*

Most of the oxides of nitrogen are emitted to the atmosphere as a result of fuel combustion. The major source of these pollutants are automobiles and larger fuel-burning installations. Small fuel-burning units also emit some nitrogen oxides. For this reason, higher concentrations of these gases would be expected during the autumn sampling period when emissions from space-heating sources are at a higher level.

The prediction of higher concentrations was affirmed during this study. Average hourly concentrations in the summer sampling period ranged from 0.01 to 0.05 ppm, as compared to 0.05 to 0.11 ppm in the autumn period. A considerable build-up of these pollutants occurred during a period of atmospheric stability that ended on the morning of November 16. During this period, a maximum

*Nitric oxide and nitrogen dioxide were determined separately; for purposes of this description values shown are sums of the two constituents.

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Figure 4. Smog formation in Providence August 10, 1961 - visibility reduced by pollution accumulation at 8:30 am (upper), but cleared by dispersion at 12:30 pm (lower)

concentration of 0.38 ppm was recorded. Similar meteorological conditions in the summer phase sampling resulted in accumulation of only 0.12 ppm of these pollutants.

Nearly nothing is known of the chronic toxicity of nitric oxide. This is due to its relatively rapid oxidation to nitrogen dioxide, which makes study of its effects difficult. Nitrogen dioxide is considered more toxic than nitric oxide. Workmen in Russia have suffered adverse effects after 3 to 5 years of exposure to nitrogen dioxide at concentrations generally below 2.8 ppm, and workmen in the United States from exposure to slightly higher levels.[8] In light of these and other facts, the State of California is considering (but has not yet adopted) a nitrogen dioxide concentration of 3 ppm as a standard "serious" pollution level It should be noted

GPO 821199-3

that an "adverse" level is not cited, since any concentration that produces discomfort in humans (the adverse level) is accompanied by effects that are classified as "serious."

A significant aspect of pollution by oxides of nitrogen is the part they play in photochemical smog reactions. These pollutants react with hydrocarbons in the atmosphere under the influence of solar radiation to produce "oxidant type" pollutants that have adverse effects on humans, plants, and visibility.

Carbon Monoxide

Carbon monoxide is a product of incomplete combustion. At levels much higher than those normally found in ambient air, carbon monoxide seriously interferes with the oxygen transport of the blood. This effect is evident after 8 or more hours of exposure to 30 ppm or after 1 hour or more of exposure to 120 ppm.[8]

The chief source of carbon monoxide is the automobile. Carbon monoxide is emitted from automobile exhaust at a concentration of about 3.8 percent by volume, or 38,000 ppm.[8] It is readily evident that a large dilution would be required to reduce carbon monoxide from automobiles to safe levels. The locations where high carbon monoxide concentrations are likely to occur are the downtown shopping areas, i.e. locations where high density automobile traffic, combined with reduction of air movement by high buildings, may result in high concentrations of the gas.

Average concentrations of carbon monoxide found in Providence at the roof sampling station were generally less than 1 ppm. The greatest concentration found was 6 ppm in a single sample. These values are considerably below those that are expected to cause detrimental effects.

One can estimate the future potential auto exhaust problem by projecting from past records. By 1970, an estimated 290 million gallons of gasoline will be consumed annually in the State of Rhode Island (Figure 5), as compared with 250 million gallons in 1959.[11] This represents an over-all increase of 8 percent, and the growth of Providence likely will exceed the average for the State. If emissions per gallon of gasoline used remain constant, a proportional increase in emitted pollutants will result.

AIR POLLUTION POTENTIAL

Normality of Weather During Sampling

Weather conditions during the sampling periods were near normal. Temperatures were slightly warmer than normal during both sampling periods. In August 1961 the average temperature was 71.0°F, compared with a normal of 69.4°F. Similarly, the average temperature in November 1961 was 43.6°F, compared with a normal of 42.6°F.[6, 12]

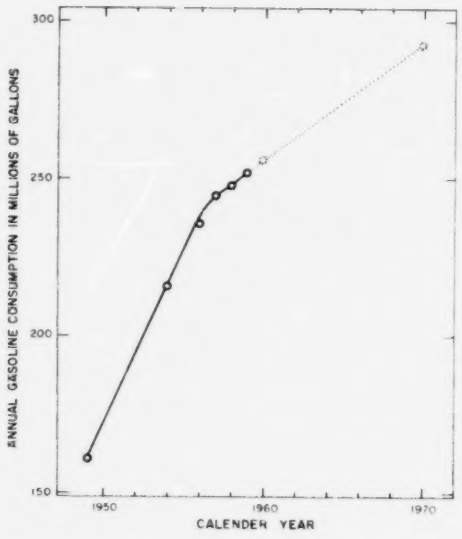

Figure 5. Annual gasoline consumption for State of Rhode Island (1949-1970)

The heating degree-days substantiate the normality of the two sampling periods. August 1961 had 6 degree-days, compared with a normal of 26 (neither reflects a need for space heating); November 1961 registered 633 degree-days, compared with a normal of 672.[6, 12]

Precipitation and sunshine also were about normal during the sampling periods. Total precipitation in August 1961 was 3.86 inches and occurred on 9 days. Normally, Providence has a total of 3.63 inches in 9 days. The November sampling period had 7 days with precipitation for a total of 3.10 inches of rain, whereas the normal for that period is 3.74 inches on 10 days.[6, 12] Normal sunshine for August is 60 percent of that possible. A value of 56 percent was observed for the 1961 sampling period. For November, the normal amount of sunshine is 53 percent of possible. The percent sunshine for the sampling period was 48.[6, 12]

Wind speeds showed a tendency to be somewhat greater than normal during the sampling periods (Table 3). A comparison with a 5-year summary of wind data from November 1949 to October 1954 showed wind speeds averaged 18 percent greater than normal in the August sampling period and 25 percent greater than normal in the November sampling period. Based on 44 years of data collected in Providence, hourly wind speeds for August and November averaged 8.9 and 11.0 mph, respectively.

Clear skies and light surface winds at night favor formation

Table 3. COMPARISON OF WIND DATA DURING SAMPLING PERIODS WITH 5-YEAR SUMMARIES.

Weather parameter	August		November	
	1950-54[a]	1961[b]	1949-53[a]	1961[b]
Prevailing wind direction	SW	S	NW	NNW
Percent of winds ≤7 mph	47	33	45	27
Percent of winds ≤3 mph	17	5	16	4.4
Percent of calms	7	4	5	4
Average wind speed	8.2	9.7	9.2	11.5

[a]Reference 13.
[b]Reference 6.

of nocturnal radiation-type inversions over land. Hosler related cloud cover and wind speed to inversion frequency and found a definite relationship.[14] These tabulated data for summer and fall were compared with that for the August and November 1961 sampling periods (Table 4). Simultaneous occurrence of clear skies and low wind speeds would determine the maximum frequency of inversion conditions. Thus, the maximum possible occurrence of inversions would be limited to the parameter (wind speed less than 7 miles per hour or cloud cover of less than 3/10) that occurred least often.

Table 4. COMPARISON OF THE NIGHTTIME STABILITY OF THE ATMOSPHERE DURING SAMPLING PERIODS WITH DATA ESTIMATED FROM 5-YEAR SUMMARIES.

Weather parameter	Average summer season nighttime[a]	August 1961 2000 to 0400 hr[b]	Average fall season nighttime[c]	November 1961 1800 to 0600 hr[b]
Percent of winds ≤7 mph	65	55	54	71
Percent of cloud cover ≤3/10	45	47	51	69

[a]Reference 15.
[b]Reference 7.
[c]Reference 14.

Nighttime cloud cover of less that 3/10 occurred 47 percent of the time in August 1961, essentially the same as the normal 45 percent. During November 1961 the atmosphere was possibly more stable than normal; again the controlling factor was cloud cover. Thus, stability of the atmosphere during the sampling periods was near normal.

Dispersion Characteristics

A study of low-level-inversion frequency has shown that the

Providence area can expect inversion conditions to exist about 25 percent of the time (Table 5).[14]

Table 5. FREQUENCY AND DURATION OF INVERSION CONDITIONS

Season	Percent of total hours inversions occur		Duration of inversions (longest 10%)
	Estimated for Providence[a]	Measured in Middletown, Connecticut[b]	Measured in Middletown, Connecticut[b]
Winter	25	33	14 hours or longer
Spring	20	25	13 hours or longer
Summer	25	27	17 hours or longer
Fall	30	32	19 hours or longer
Annual	25	29	----

[a]Reference 14.
[b]Reference 16.

A detailed study of the weather conditions that relate to dispersion of pollutants was conducted by the Weather Bureau at the CANEL site near Middletown, Connecticut, at the request of the Atomic Energy Commission.[16] Since the special weather station for Middletown was located in the Connecticut River Valley, however, only certain data would be representative of Providence. In a 2-year study of the lapse rate distribution for the area, an instrumented 200-foot tower and a tethered balloon with a wiresonde attached were used. The maximum duration of an inversion during this 2-year study occurred in the winter and lasted for 53 consecutive hours. The percentage of hours in each season during which an inversion condition existed in Middletown was recorded (Table 5). They were much the same as estimated by Hosler for the Rhode Island area. It should be noted that Hosler used the Middletown data along with other data for estimating inversion frequency in the area.

Lapse rate observations at the CANEL site indicated somewhat less-stable conditions than were predicted for Providence by the Pasquill-Turner estimation. It should be noted, however, that the CANEL data were interpreted conservatively; therefore, there probably is less real difference than would be apparent between the estimation and the CANEL data. From July 31 through August 17, 1961, 35 percent of the lapse rate observations showed inversions and from October 31 through November 17, 1961, 50 percent were inversions.[15]

Inversion conditions, once they occur, can be expected to endure for less than 1 hour up to several days. The most severe season is fall, when 10 percent of the inversions can be expected

to persist for 19 hours or longer (Table 5).

The two longest periods of atmospheric inversion that existed during the air sampling periods in August and November, 1961, were reviewed. On the night of August 9-10, an inversion lasted for 10 hours (estimated by the Pasquill-Turner method[10]). The estimate was supported by observations at the CANEL site, where inversion conditions lasted 15 hours.[15] Inversion conditions are expected to occur on about one day in four in the summer and about half of the inversions would be expected to last 10 hours or more.[16] Thus, on the average, on one day in eight at least a 10-hour inversion would occur, and pollutant levels of gases and particulate matter, excepting oxidants, would approximate those on August 10, 1961. For a build-up of oxidants to occur, two conditions other than the inversion must exist: first, there must be a sufficient concentration of pollutants in the air, and second, there must be sufficient sunlight to cause atmospheric reactions of the pollutants. Thus, high oxidant levels equal to or greater than those in the maximum summer samples occur on an average of one day in 16 rather than one in eight, since the sun shines only about 60 percent of the time during daylight hours.

During the pollution accumulation on the night of November 15-16, 1961, an inversion lasted 14 hours (estimated by Pasquill-Turner method[10]). The estimate was supported by observations at the CANEL site, where inversion conditions lasted 15 hours.[15] Inversions are expected to occur during about one-third of the time in the fall or winter season or, in other words, about one day in three. About one-half of the inversions in the fall and one-third of those in the winter could be expected to last 14 hours. Thus, on one day in six in the fall and one day in nine in the winter, pollutant levels would be expected to equal or exceed those found on November 16, 1961. It is important that the degree-days in November 1961 were only one-half the normal for the coldest month, January. Thus, since more fuel is consumed for heat, additional sulfur dioxide, oxides of nitrogen, and particulate matter would be emitted and pollution levels would rise accordingly. Suspended particulate determinations for 1954-1957 by the National Air Sampling Network substantiate the expected rise of pollutant levels in the winter; the November average was 67 $\mu g/m^3$, the December averaged 89, January 114, and February 92. However, particulate matter, sulfur dioxide, and oxides of nitrogen levels, which would rise and potentially pose a major problem in mid-winter, were not particularly high in November. A severe problem would not likely result.

The frequency of occurrence of stagnating anticyclones over the eastern United States has been tabulated by Korshover.[17] The monthly distribution of long-term stagnation conditions in Providence for a 21-year period (from 1936 to 1956) was as follows: April, 1; August, 1; September, 2; October, 4; November, 1. Over

the 21-year period the Providence area experienced nine stagnation periods that lasted 4 days or longer, with a total of 40 stagnation days.

Thus, every 2 years or so a stagnant air mass would be expected to occur and cause an extraordinary pollution build-up. Distressful conditions for the inhabitants of the area could prevail for 4 or more days.

APPENDIX A

TABULATION OF POLLUTION MEASUREMENTS

TABLE A1. SULFUR DIOXIDE SAMPLING RESULTS IN PARTS PER MILLION[a] (Phase I)

Date (1961)	Time (EDT)												Daily max	Daily avg
	0000	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200		
7/31					0.02	0.06	0.06	0.05	0.01	0.02	0.01	0.01	0.06	0.03
8/1	0.01	0.03	0.01	0.02	0.02	0.01	<0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.02
8/2	0.01	0.02	0.01	-	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01
8/3	<0.01	0.01	0.02	0.04	0.02	0.01	0.02	0.04					0.04	0.02
8/4				0.06	0.07	0.06	0.02	0.02					0.07	0.05
8/7				0.01	0.01	0.01	0.03	0.02					0.03	0.02
8/8				0.01	0.01	0.01	<0.01	<0.01					0.01	0.01
8/9				0.01	0.01	0.01	0.01	<0.01					0.01	0.01
8/10				0.03	0.07	0.07	0.01	0.01					0.07	0.04
8/11				0.02	0.02	0.02	0.02	0.01					0.02	0.02
8/14				0.02	0.01	0.01	<0.01	<0.01					0.02	0.01
8/15				0.02	0.01	0.01	0.01	0.01					0.02	0.01
8/16				0.01	0.01	0.01	<0.01	0.01					0.01	0.01
8/17				0.01	0.03	0.01	0.01	0.0					0.03	0.01
8/18				0.02	0.03	0.02	0.02	0.04					0.04	0.03
Maximum	0.01	0.03	0.02	0.06	0.07	0.07	0.06	0.05	0.02	0.02	0.02	0.03		
Average	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.01	0.02	0.01	0.02		

[a]Average of all samples collected: 0.02 (note that the number of daytime samples greatly exceeds the number of nighttime samples).

TABLE A2. SULFUR DIOXIDE SAMPLING RESULTS IN PARTS PER MILLION[a] (Phase II)

Date (1961)	Time (EST)												Daily max	Daily avg
	0000	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200		
10/31					0.02	0.07	0.02	0.01	0.02				0.07	0.03
11/1					0.03	0.02	0.13	0.05	0.08				0.13	0.06
11/2					0.11	0.04	0.06	0.06	0.04				0.11	0.06
11/3					0.04	0.04	0.01	0.06	0.04				0.06	0.04
11/6					0.17	0.08	0.07	0.03	0.03				0.17	0.08
11/7					0.11	0.08	0.04	0.06	0.03	0.07	0.16	0.16	0.16	0.09
11/8	0.16	0.07	0.09	0.09	0.12	0.13	0.09	0.06	0.08	0.04	0.03	0.05	0.16	0.08
11/9	0.10	0.09	0.11	0.13	0.10	0.10	0.10	0.12	0.10	0.13	0.12	0.15	0.15	0.11
11/10	0.13	0.08	0.07	0.09	0.11	0.04	0.03	0.04	0.04				0.13	0.07
11/11					0.08	0.06	0.06	BMD[b]	0.04				0.08	0.05
11/13					0.05	0.05	0.03	0.03	0.03				0.05	0.03
11/14					0.03	0.03	0.03	0.04	0.04				0.04	0.03
11/15					0.04	0.04	0.01	0.04	0.04				0.04	0.03
11/16					0.17	0.19	0.08	0.05	0.04				0.19	0.11
11/17					0.04	0.04	0.01	0.07	0.06				0.07	0.04
Maximum	0.16	0.09	0.11	0.13	0.17	0.19	0.13	0.12	0.10	0.13	0.16	0.16		
Average	0.13	0.08	0.09	0.10	0.08	0.07	0.05	0.05	0.08	0.10	0.12	0.12		

[a]Average of all samples collected: 0.07 (note that the number of daytime samples greatly exceeds the number of nighttime samples).

[b]BMD - Below minimum detectable limits of analytical method.

TABLE A3. TOTAL OXIDANT SAMPLING RESULTS IN PARTS PER MILLION[a] (Phase I)

Date (1961)	Time (EDT)												Daily max	Daily avg
	0000	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200		
7/31					0.06	0.10	0.12	0.12	0.12	0.14	0.05	0.04	0.14	0.09
8/1	0.04	0.03	0.03	0.02	0.01	0.07	0.08	0.12	0.15	0.13	0.09	0.03	0.15	0.07
8/2	0.04	0.03	0.03	0.03	0.03	0.08	0.12	0.12	0.06	0.03	0.02	0.03	0.12	0.05
8/3	0.04	0.04	0.04	0.03	0.02	0.04	0.04	0.04					0.04	0.04
8/4				0.04	0.04	0.04	0.05	0.10					0.10	0.05
8/7				0.03	0.04	0.06	0.10	0.10					0.10	0.07
8/8				0.04	0.07	0.08	0.10	0.12					0.12	0.08
8/9				0.06	0.04	0.08	0.11	0.09					0.11	0.08
8/10				0.12	0.18	0.14	0.27	0.25					0.27	0.19
8/11				0.02	0.03	0.10	0.12	0.12					0.12	0.08
8/14				0.01	0.03	0.04	0.06	0.08					0.08	0.04
8/15				0.08	0.08	0.11	0.14	0.14					0.14	0.11
8/16				0.03	0.07	0.09	0.10	0.10					0.10	0.08
8/17				0.02	0.02	0.05	0.08	0.15					0.15	0.08
8/18				0.02	0.04	0.09	0.12	0.13					0.13	0.08
Maximum	0.04	0.04	0.04	0.12	0.18	0.14	0.27	0.25	0.15	0.14	0.09	0.04		
Average	0.04	0.03	0.03	0.04	0.05	0.08	0.11	0.12	0.11	0.10	0.05	0.03		

[a]Average of all samples collected: 0.07 (note that the number of daytime samples greatly exceeds the number of nighttime samples).

TABLE A4. TOTAL OXIDANTS SAMPLING RESULTS IN PARTS PER MILLION[a] (Phase II)

Date (1961)	Time (EST)												Daily max	Daily avg
	0000	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200		
10/31					-	0.10	0.16	0.12	0.02				0.16	0.10
11/1					0.04	0.07	0.04	0.04	0.04				0.07	0.05
11/2					BMD[b]	0.04	0.06	0.06	0.06				0.06	0.04
11/3					0.02	0.04	0.05	0.04	0.04				0.05	0.04
11/6					0.03	0.05	0.05	0.02	0.01				0.05	0.03
11/7					0.07	0.07	0.07	0.05	0.06	0.04	0.03	0.04	0.07	0.05
11/8	0.04	0.03	0.03	0.03	0.01	0.02	0.08	0.03	0.02	0.02	0.02	0.02	0.08	0.03
11/9	0.03	0.03	0.03	0.02	0.02	0.05	0.06	0.06	0.02	0.05	0.02	0.04	0.06	0.04
11/10	0.03	0.04	0.03	0.04	0.05	0.04	0.02	0.01	0.05				0.05	0.03
11/11					0.05	0.05	0.05	0.07	0.05				0.07	0.05
11/13					0.06	0.07	0.10	0.07	0.05				0.10	0.07
11/14					0.04	0.04	0.05	0.04	0.01				0.05	0.04
11/15					0.01	0.04	0.04	0.04	0.04				0.04	0.03
11/16					BMD[b]	0.10	0.01	0.01	BMD[b]				0.10	0.02
11/17					0.01	0.0	0.10	0.08	0.11				0.11	0.07
Maximum	0.04	0.04	0.03	0.04	0.07	0.10	0.16	0.12	0.11	0.05	0.03	0.04		
Average	0.03	0.03	0.03	0.03	0.03	0.06	0.06	0.04	0.04	0.04	0.02	0.03		

[a]Average of all samples collected: 0.04 (note that the number of daytime samples greatly exceeds the number of nighttime samples).

[b]BMD - Below minimum detectable limits of analytical method.

TABLE A5. NITRIC OXIDE SAMPLING RESULTS IN PARTS PER MILLION[a] (Phase I)

Date (1961)	Time (EDT)												Daily max	Daily avg
	0000	0200	0400	06 0	0800	1000	1200	1400	1600	1800	2000	2200		
7/31					0.05	0.05	0.05	0.01	<0.01	<0.01	0.01	<0.01	0.05	0.02
8/1	<0.01	0.01	<0.01	0.01	0.02	0.01	0.01	0.01	<0.01	<0.01	<0.01	0.02	0.02	0.01
8/2	BMD[b]	BMD[b]	0.01	0.01	0.02	0.01	BMD[b]	<0.01	<0.01	0.01	0.01	0.01	0.02	0.01
8/3	<0.01	<0.01	<0.01	0.01	0.02	0.03	0.04	0.02					0.04	0.02
8/5				0.02	0.02	0.02	0.01	0.01					0.02	0.02
8/7				0.02	0.03	0.01	0.01	<0.01					0.03	0.01
8/8				0.01	0.01	0.01	0.01	0.01					0.01	0.01
8/9				0.01	0.01	<0.01	<0.01	BMD[b]					0.01	<0.01
8/10				0.01	0.01	0.01	BMD[b]	<0.01					0.01	0.01
8/11				0.01	0.01	<0.01	BMD[b]	BMD[b]					0.01	<0.01
8/14				0.02	0.01	0.02	0.02	0.02					0.02	0.02
8/15				0.02	0.02	0.01	<0.01	<0.01					0.02	0.01
8/16				0.01	0.01	0.01	<0.01	<0.01					0.01	0.01
8/17				BMD[b]	0.02	0.01	<0.01	BMD[b]					0.02	0.01
8/18				0.01	0.02	0.02	0.01	0.02					0.02	0.02
Maximum	<0.01	0.01	<0.01	0.02	0.05	0.05	0.05	0.02	<0.01	0.01	0.01	0.02		
Average	<0.01	<0.01	<0.01	0.01	0.02	0.01	0.01	0.01	<0.01	<0.01	0.01	0.01		

[a]Average of all samples collected 0.01 (note that the number of daytime samples greatly exceeds the number of nighttime samples).

[b]BMD - Below minimum detectable limits of analytical method.

TABLE A6. NITRIC OXIDE SAMPLING RESULTS IN PARTS PER MILLION[a] (Phase II)

Date (1964)	Time (EST)												Daily max	Daily avg
	0000	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200		
10/31					0.02	0.02	0.01	0.01	0.01				0.02	0.01
11/1					0.02	BMD[b]	0.02	0.01	0.01				0.02	0.01
11/2					0.01	0.01	0.08	0.03	0.02				0.08	0.03
11/3					0.01	BMD[b]	BMD[b]	BMD[b]	0.01				0.01	<0.01
11/6					0.03	0.01	BMD[b]	0.03	0.01				0.03	0.02
11/7					0.08	0.05	0.07	0.08	0.08	0.07	0.05	0.03	0.08	0.07
11/8	0.04	0.05	0.02	0.04	0.09	0.04	0.03	0.02	0.04	0.05	0.05	0.05	0.09	0.04
11/9	0.05	0.05	0.03	0.05	0.05	0.05	0.06	0.03	0.07	0.05	0.03	0.03	0.07	0.05
11/10	0.02	0.02	0.02	0.03	0.04	0.02	0.01	0.03	0.08				0.08	0.03
11/11					0.03	0.03	0.02	0.02	0.04				0.04	0.03
11/13					0.04	0.04	0.01	0.01	0.02				0.04	0.02
11/14					0.05	0.03	0.02	0.03	0.09				0.09	0.04
11/15					0.09	0.07	0.03	0.02	0.03				0.09	0.05
11/16					0.28	0.08	0.03	0.03	0.05				0.28	0.10
11/17					0.03	0.02	0.02	0.02	0.05				0.05	0.03
Maximum	0.05	0.05	0.03	0.05	0.28	0.08	0.08	0.08	0.09	0.07	0.05	0.05		
Average	0.04	0.04	0.02	0.04	0.06	0.03	0.03	0.02	0.04	0.06	0.04	0.04		

[a]Average of all samples collected: 0.04 (note that the number of daytime samples greatly exceeds the number of nighttime samples).

[b]BMD - Below minimum detectable limits of analytical method.

TABLE 37. NITROGEN DIOXIDE SAMPLING RESULTS IN PARTS PER MILLION[a] (Phase I)

Date (1961)	Time (EDT)												Daily max	Daily avg
	0000	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200		
7/31					0.01	0.05	0.05	0.02	0.01	0.02	0.04	0.01	0.05	0.03
8/1	0.03	0.03	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.03	0.04	0.04	0.02
8/2	0.02	0.02	0.01	0.02	0.03	0.01	0.01	0.01	0.01	0.02	0.03	0.02	0.03	0.02
8/3	0.02	0.01	0.01	0.02	0.03	0.03	0.04	0.03					0.04	0.02
8/4				0.02	0.03	0.04	0.03	0.03					0.04	0.03
8/7				0.03	0.05	0.03	0.02	0.01					0.05	0.03
8/8				0.01	0.02	0.01	0.01	0.01					0.02	0.01
8/9				0.03	0.03	0.07	0.01	0.01					0.03	0.02
8/10				0.07	0.11	0.05	0.02	0.02					0.11	0.05
8/11				0.02	0.02	0.01	0.01	0.01					0.02	0.01
8/14				0.01	0.02	0.01	0.01	0.01					0.02	0.01
8/15				0.06	0.04	0.01	0.01	0.01					0.06	0.02
8/16				0.01	0.02	0.02	0.01	0.01					0.02	0.01
8/17				BMD[b]	0.03	0.02	0.02	0.01					0.03	0.02
8/18				0.01	0.02	0.02	0.01	0.05					0.05	0.02
Maximum	0.03	0.03	0.01	0.07	0.11	0.05	0.05	0.05	0.01	0.02	0.04	0.04		
Average	0.02	0.02	0.01	0.02	0.03	0.02	0.02	0.02	0.01	0.02	0.03	0.02		

[a]Average of all samples collected: 0.02 (note that the number of daytime samples greatly exceeds the number of nighttime samples).

[b]BMD - Below minimum detectable limits of analytical method.

TABLE A8. NITROGEN DIOXIDE SAMPLING RESULTS IN PARTS PER MILLION[a] (Phase II)

Date (1961)	Time (EST)												Daily max	Daily avg
	0000	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200		
10/31					0.01	0.01	0.01	0.01	0.01				0.01	0.01
11/1					0.01	BMD[b]	0.01	0.01	0.01				0.01	0.01
11/2					0.01	0.01	0.01	0.02	0.01				0.02	0.01
11/3					0.01	BMD[b]	BMD[b]	BMD[b]	0.01				0.01	<0.01
11/6					0.01	0.01	0.01	0.02	0.01				0.02	0.01
11/7					0.07	0.04	0.04	0.07	0.07	0.05	0.05	0.05	0.07	0.05
11/8	0.05	0.05	0.05	0.05	0.07	0.03	0.02	0.03	0.06	0.07	0.07	0.07	0.07	0.05
11/9	0.07	0.07	0.03	0.04	0.04	0.05	0.03	0.03	0.05	0.03	0.01	0.02	0.07	0.04
11/10	0.04	0.01	0.02	0.02	0.03	0.01	0.02	0.01	0.05				0.05	0.02
11/13					0.03	0.02	0.01	0.01	0.04				0.04	0.02
11/15					0.04	0.07	0.03	0.03	0.02				0.07	0.04
11/14					0.08	0.05	0.04	0.05	0.10				0.10	0.06
11/15					0.04	0.03	0.03	0.02	0.07				0.07	0.04
11/16					0.10	0.28	0.07	0.07	0.03				0.28	0.13
11/17					0.05	0.04	0.04	0.06	0.09				0.09	0.06
Maximum	0.07	0.07	0.05	0.05	0.10	0.28	0.07	0.07	0.10	0.07	0.07	0.07		
Average	0.05	0.04	0.03	0.04	0.04	0.04	0.02	0.03	0.04	0.05	0.04	0.05		

[a]Average of all samples collected: 0.04 (note that the number of daytime samples greatly exceeds the number of nighttime samples).

[b]BMD - Below minimum detectable limits of analytical method.

TABLE A9. CARBON MONOXIDE SAMPLING RESULTS IN PARTS PER MILLION[a] (Phase I)

Date (1961)	Time (EDT)												Daily max	Daily avg
	0000	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200		
7/31					1.0	1.3	0.7	0.5	0.8	0.8	0.8	BMD[b]	1.3	0.7
8/1	BMD[b]	BMD[b]	BMD[b]	0.4	0.7	0.7	0.7	2.0	1.3	0.8	0.8	0.8	2.0	0.7
8/2	BMD[b]	BMD[b]	0.1	0.6	1.5	0.5	0.7	0.7	1.3	1.0	0.8	BMD[b]	1.5	0.6
8/3	0.1	BMD[b]	BMD[b]	0.1	1.0	1.0	2.0	0.7					2.0	0.6
8/4				0.5	1.1	2.2	1.2	1.2					2.2	1.2
8/7				1.5	2.0	1.0	0.4	0.5					2.0	1.1
8/8				0.5	0.5	0.2	0.2	BMD[b]					0.5	0.3
8/9				0.6	0.8	0.7	BMD[b]	BMD[b]					0.8	0.4
8/10				1.0	6.0	1.0	0.2	0.7					6.0	1.8
8/11				0.2	1.0	0.6	BMD[b]	BMD[b]					1.0	0.4
8/14				BMD[b]	0.3	BMD[b]	0.2	BMD[b]					0.3	0.1
8/15				0.1	0.4	BMD[b]	0.5	0.5					0.5	0.3
8/16				0.2	0.6	0.7	0.7	0.5					0.7	0.5
8/17				BMD[b]	0.8	0.3	0.5	0.1					0.8	0.3
8/18				0.2	1.0	0.4	0.4	0.2					1.0	0.4
Maximum	0.1	BMD[b]	0.1	1.5	6.0	2.2	2.0	2.0	1.3	1.0	0.8	0.8		
Average	BMD[b]	BMD[b]	BMD[b]	0.4	1.2	0.7	0.6	0.5	1.1	0.9	0.8	0.3		

[a]Average of all samples collected: 0.6 (note that the number of daytime samples greatly exceeds the number of nighttime samples).

[b]BMD - Below minimum detectable limits of analytical method.

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TABLE A10. CARBON MONOXIDE SAMPLING RESULTS IN PARTS PER MILLION[a] (Phase II)

Date (1961)	Time (EST)												Daily max	Daily avg
	0000	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200		
10/31					0.8	0.3	0.3	0.4	0.8				0.8	0.5
11/1					1.0	0.4	0.3	0.4	0.4				1.0	0.5
11/2					0.6	0.5	0.3	0.4	0.3				0.6	0.4
11/3					1.1	0.8	0.8	0.7	0.8				1.1	0.8
11/6					2.5	0.8	1.0	1.0	0.8				2.5	1.2
11/7					0.8	0.4	0.4	0.4	0.8	1.0	0.5	0.5	1.0	0.6
11/8	0.7	0.4	0.4	0.4	0.7	0.4	0.4	0.4	0.4	0.8	0.8	1.2	1.2	0.6
11/9	0.4	0.4	0.4	0.8	0.8	0.8	0.4	0.4	0.4	0.4	0.4	0.4	0.8	0.5
11/10	0.4	0.3	0.3	0.5	0.4	0.3	0.4	0.4	0.8				0.8	0.5
11/11					0.4	1.0	0.7	0.7	0.8				1.0	0.7
11/13					1.3	0.8	0.4	BMD[b]	0.4				1.3	0.6
11/14					0.8	0.4	0.4	0.4	0.8				0.8	0.5
11/15					0.4	0.4	0.8	0.4	0.8				0.8	0.6
11/16					1.6	0.8	0.4	0.4	0.8				1.6	0.8
11/17					0.8	0.4	0.4	0.4	0.8				0.8	0.6
Maximum	0.7	0.4	0.4	0.8	2.5	1.0	1.0	1.0	0.8	1.0	0.8	1.2		
Average	0.5	0.4	0.4	0.6	0.9	0.9	0.5	0.5	0.7	0.7	0.6	0.7		

[a] Average of all samples collected: 0.6 (note that the number of daytime samples greatly exceeds the number of nighttime samples).

[b] BMD - Below minimum detectable limits of analytical method.

TABLE A11. SOILING, SUSPENDED PARTICULATES, AND DUSTFALL SAMPLING RESULTS (Phase I)
Time (EST)

Date (1961)	Soiling index, Cohs per 1000 linear feet of air, Time (EDT) 0000-0400	0400-0800	0800-1200	1200-1600	1600-2000	2000-2400	Daily max	Daily avg	Suspended particulates,[a] μg/m³	Dustfall
7/31	-	-	0.8	0.8	0.7	0.6	0.8	0.7	118	A single sample of dustfall was collected from July 31 through August 18, 1961. Total dustfall measured 18.7 tons per square mile per month, with 44% insoluble and 56% soluble material.
8/1	0.6	0.4	0.5	0.2	0.7	0.6	0.7	0.5	86	
8/2	0.6	0.7	0.5	0.2	0.7	0.4	0.7	0.5	89	
8/3	0.4	0.7	1.2	0.7	1.0	0.7	1.2	0.8	78	
8/4	0.6	0.8	0.7	0.8	0.7	0.8	0.8	0.7	83	
8/5	1.4	0.6	0.6	0.4	0.5	0.4	1.4	0.6	-	
8/6	0.4	0.2	0.5	0.4	0.2	0.4	0.5	0.3	-	
8/7	0.5	0.6	0.7	0.7	0.5	0.5	0.7	0.6	60	
8/8	0.6	0.8	0.6	0.2	0.5	0.7	0.8	0.6	61	
8/9	0.7	0.8	1.0	0.5	0.6	0.6	1.0	0.7	75	
8/10	1.0	1.5	2.2	0.6	1.0	0.8	2.2	1.2	136	
8/11	0.5	0.7	0.6	0.6	0.6	0.4	0.7	0.6	61	
8/12	0.4	0.5	0.7	0.4	0.4	0.6	0.7	0.5	-	
8/13	0.7	0.2	0.2	0.2	0.2	0.4	0.7	0.3	-	
8/14	0.2	0.2	0.2	0.1	0.1	0.4	0.4	0.2	33	
8/15	0.7	0.8	0.7	0.5	0.5	0.4	0.8	0.6	69	
8/16	0.5	0.4	0.7	0.5	0.6	0.7	0.7	0.6	64	
8/17	0.4	0.7	0.6	0.6	0.6	0.4	0.7	0.4	70	
8/18	0.7	0.8	1.2	1.0	0.8	0.7	1.2	0.8	120	
4-Hour max	1.4	1.5	2.2	1.0	1.0	0.8			-	
4-Hour avg	0.6	0.6	0.7	0.5	0.6	0.6			Daily average: 76	

[a]Obtained with high-volume sampler and reported on day of completion for 24-hour period (1600 to 1600 hr).

TABLE A12. SOILING, SUSPENDED PARTICULATES, AND DUSTFALL SAMPLING RESULTS (Phase II)

Date (1961)	Soiling index, Cohs per 1000 linear feet of air — Time (EST) 0000-0400	0400-0800	0800-1200	1200-1600	1600-2000	2000-2400	Daily max	Daily avg	Suspended particulates,[a] μg/m³	Dustfall
10/31			0.2	0.1	0.8	0.5	0.8	0.5	-	A single sample of dustfall was collected from October 31 through November 17, 1961. Total dustfall measured 21.3 tons per square mile per month, with 67% insoluble and 33% soluble material.
11/1	0.4	0.6	0.4	0.3	0.5	0.4	0.6	0.5	74	
11/2	0.7	0.7	0.5	0.6	0.8	0.7	0.8	0.7	72	
11/3	0.7	0.5	0.7	0.4	0.6	0.4	0.7	0.6	87	
11/4	0.4	0.7	0.7	0.5	0.7	0.5	0.7	0.6	-	
11/5	BMD[b]	0.4	0.5	BMD[b]	0.4	0.2	0.5	0.3	-	
11/6	0.5	0.3	1.1	0.8	0.6	0.4	1.1	0.6	127	
11/7	0.3	0.5	0.7	0.7	0.7	0.6	0.7	0.6	58	
11/8	0.7	1.4	0.8	0.7	0.8	0.7	1.4	0.9	87	
11/9	0.7	0.6	0.7	0.5	0.4	0.5	0.7	0.6	116	
11/10	0.4	1.1	0.5	0.6	0.2	0.2	1.1	0.5	99	
11/11	0.9	1.8	1.9	1.8	1.5	0.7	1.9	1.4	56	
11/12	1.0	1.3	1.0	BMD[b]	0.6	0.7	1.3	0.8	121	
11/13	0.7	1.0	BMD[b]	0.9	0.4	0.7	1.0	0.6	105	
11/14	0.7	0.2	0.7	0.9	0.9	0.6	0.9	0.7	57	
11/15	0.1	0.6	0.4	0.7	1.3	1.1	1.3	0.7	67	
11/16	1.5	1.2	1.6	2.3	0.7	0.7	2.3	1.3	148	
11/17	- Inoperative			-	-	-			57	
4-Hour max	1.5	1.2	1.6	2.3	1.5	1.1			-	
4-Hour avg	0.6	0.8	0.7	0.7	0.7	0.6			Daily Average: 89	

[a] Obtained with high-volume sampler and reported on day of completion for 24-hour period (1600 to 1600 hr).
[b] BMD - Below minimum detectable limits of analytical method.

APPENDIX B

ANALYTICAL PROCEDURES

Soiling Index

Suspended particulates

Dustfall

Sulfur dioxide

Oxidants

Oxides of nitrogen

Carbon monoxide

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ANALYTICAL PROCEDURES

Soiling Index

Continuous soiling index determinations were made throughout the study with an AISI automatic strip filter paper sampler (Figure B1). Air was drawn through a 1-inch diameter circular area of a strip of Whatman #4 filter paper at a rate of approximately 0.25 cubic feet per minute for 4 hours; the filter strip was moved to a new position every 4 hours and the cycle repeated. At intervals of 2 or 3 days, the used filter paper was removed. The percent transmission of light through dirty spots, as compared with transmission through clean paper, was determined with a spot evaluator. Cohs per 1000 linear feet of air were determined directly from a calibration curve.

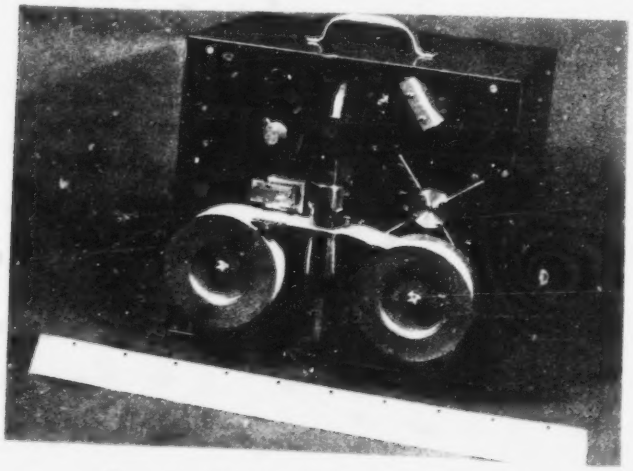

Figure B1. AISI automatic strip filter paper sampler

Suspended Particulates

Suspended particulate loadings were determined by use of a high-volume sampler (Figure B2). Air was aspirated through a tared glass fiber filter web for 24 hours at approximately 60 cfm. Initial and final flow rates for each sampling period were determined, along with actual sampling time. The filter webs were dried at 60°C overnight and reweighed. Suspended particulate concentrations were calculated in micrograms per cubic meter ($\mu g/m^3$).

Dustfall

Dustfall was collected in a wide-mouthed plastic container 10.5 inches high, 8 inches in diameter at the top, and 6.5 inches

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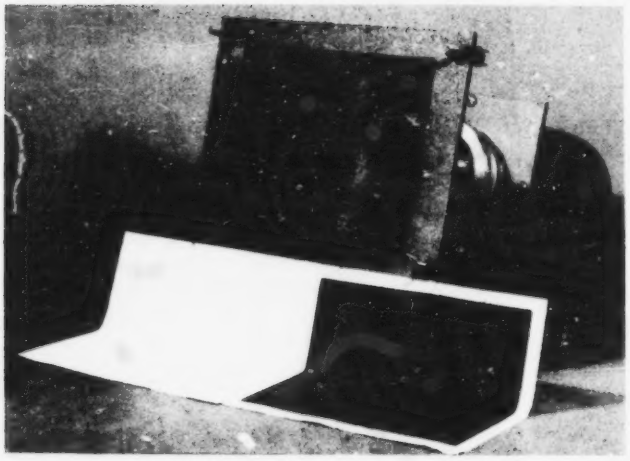

Figure B2. High-volume sampler

at the bottom (Figure B3). Five hundred milliliters of distilled water were added to prevent dispersion losses of settled particles by wind currents. During the autumn phase 50 milliliters of 95 percent isopropyl alcohol were added to the water to prevent freezing. Although not used in this study quarternary ammonium chloride can be used to inhibit biological growth.

The collected sample was filtered through a tared filter paper; the paper was dried at 110°C and reweighed. The weight gain represented water insoluble dustfall. The filtrate was evaporated to 100 milliliters on a hot plate, transferred to a tared porcelain evaporating dish, and evaporated to dryness over low heat. The evaporating dish was dried at 110°C and reweighed; the net weight gain represented water soluble dustfall.

The area of the mouth of the container was calculated, and the total sampling time was noted. Dustfall rates were reported in tons per square mile per month.

Sulfur Dioxide

Sulfur dioxide samples were collected by use of the multiple gas sampling kit shown in Figure B4, as were total oxidants, oxides of nitrogen, and carbon monoxide.

Sulfur dioxide in the samples was determined by the West and Gaeke method.[18] Ambient air was metered through a smog bubbler, which contained 10 milliliters of 0.1 M sodium tetrachloromercurate as a scrubbing agent, at a rate of 4.0 liters per minute for 30 minutes. A 10-milliliter blank was prepared at the same time as the sample and allowed to stand open to the air.

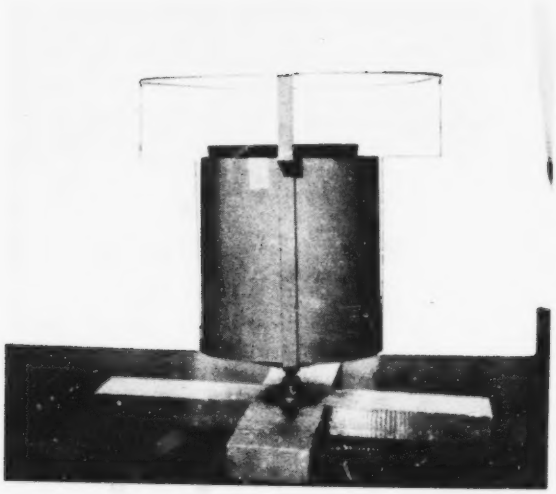

Figure B3. Dustfall collector

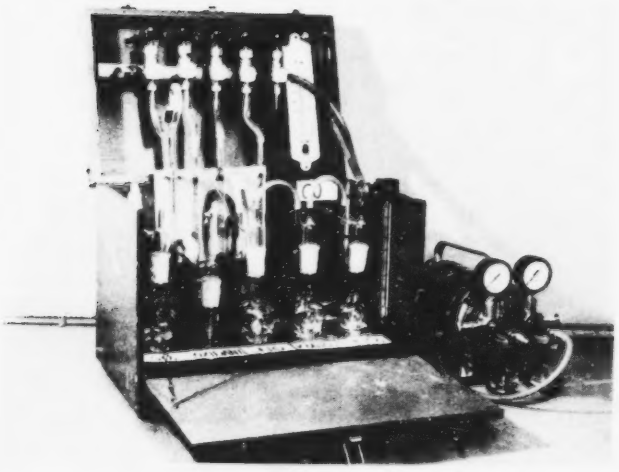

Figure B4. Multiple gas sampling kit

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At the end of the sampling period 1 milliliter of 0.02 percent bleached p-rosaniline hydrochloride (0.04 percent used in summer phase) and 1 milliliter of 0.2 percent formaldehyde solution were added; the solution was mixed and allowed to stand for 20 minutes for full color development.

Percent transmission was read on a Spectronic "20" spectrophotometer at 560 millimicrons. Sulfur dioxide concentration was determined from a standard reference curve, and reported as parts per million sulfur dioxide by volume.

Oxidants

Total oxidants were determined by the phenolphthalin method of Haagen-Smit.[19] Air was drawn through a midget impinger at a rate of 1.0 liter per minute for all oxidant samples (Figure B4). During the summer phase of sampling, a 15-minute sampling period produced sufficient color in the 0.35 percent phenophthalin absorbing solution. Because of the lower oxidant levels in the autumn, a 30-minute sampling period was used in November. Also, the phenolphthalin solution was buffered at pH 11.5 to eliminate color fading during the longer sampling period.[20] A reagent blank was prepared at the same time as the sample and allowed to stand open to the atmosphere.

The transmission of the colored solution was determined 10 minutes after collection on a Spectronic "20" spectrophotometer at 530 millimicrons, and oxidant concentrations in parts per million by volume were taken from a standard curve.

In the preparation of the standard curve, 30 percent hydrogen peroxide was diluted 1:100 and standardized with standard sodium thiosulfate. From the standarized solution a working stock containing 14 micrograms per milliliter was prepared so that each milliliter would represent 10 microliters of oxidant as hydrogen peroxide at 25°C and 1 atmosphere pressure. The working stock was diluted to predetermined levels, and after phenolphthalin and copper sulfate were added and the solutions were allowed to stand 15 minutes for color development, the percent transmittance of the dilutions were read at 530 millimicrons in the spectrophotometer.

Oxides of Nitrogen

Oxides of nitrogen were determined in a 3-unit sampling train by the Saltzman method[21] (Figure B4). In the first bubbler, nitrogen dioxide is absorbed in Saltzman reagent. In the next bubbler, the air is passed through a 2.5 percent solution of potassium permanganate, which oxidizes the nitric oxide to nitrogen dioxide. The converted nitrogen dioxide is removed in a third bubbler containing Saltzman reagent.

The air sample was drawn through smog bubblers at a rate of 0.4 liter per minute for 30 minutes. The pollutants were absorbed in 10 milliliters of Saltzman reagent containing 0.02 percent N-

(1-naphthyl)-ethylenediamine-dihydrochloride, 0.5 percent sulfanilic acid, and 1.4 percent glacial acetic acid. A blank was prepared simultaneously with the sample and allowed to remain under the same environmental conditions as the sampling bubbler.

After the 15 minutes allowed for full color development, samples were read on the Spectronic "20" spectrophotometer at 550 millimicrons and the percent transmission recorded. The concentration of nitrogen dioxide was taken from the standard curve, and the parts per million by volume calculated. The oxidized nitric oxide was determined as nitrogen dioxide from the standard curve, since the microliters of nitrogen dioxide found in bubbler No. 3 equals the microliters of nitric oxide found in the air.

Carbon Monoxide

Carbon monoxide was determined by use of Mine Safety Appliance Company indicator tubes made in accordance with a National Bureau of Standards technique.[22] Air is sampled through a carbon monoxide detector tube, which is packed with a silica gel guard that removes impurities, an indicating gel, and a second guard gel. The indicator gel is a purified silica gel-impregnated with a sulfuric acid solution of ammonium molybdate and palladous sulfate, which, on adsorption of carbon monoxide, turns uniformly from yellow to blue-green by the formation of molybdenum blue on the gel.

Air at ambient temperature was drawn through the detector tube at a rate of 0.1 liter per minute for 30 minutes (Figure B4). The amount of carbon monoxide in the sample was determined by visually comparing the used tube with a color chart. The carbon monoxide concentration was calculated in parts per million by volume.

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